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Results from the Nuclear Plant Aging Research Program: Their Use in Inspection Activities

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Prepared for
U.S. Nuclear Regulatory Commission

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Appendix A contains general information on aging-related degradation processes for the following components:
Inverters
Motors
Battery chargers
Motor control centers
Component cooling water system components (PWR)
Residual heat removal system components (BWR).
However, relatively little detail is given and the referenced reports in each section should be consulted for more specific and detailed information.

ABSTRACT

The U.S. NRC's Nuclear Plant Aging Research (NPAR) Program has determined the susceptibility to aging of components and systems, and the potential for aging to impact plant safety and availability. The NPAR Program also identified methods for detecting and mitigating aging in components.

This report describes the NPAR results which can enhance NRC inspection activities. Recommendations are provided for communicating pertinent information to NRC inspectors. These recommendations are based on a detailed assessment of the NRC's Inspection Program, and feedback from resident and regional inspectors as described within. Examples of NPAR report summaries and aging inspection guides for components and systems are included.

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SUMMARY

The Nuclear Plant Aging Research (NPAR) Program is a hardware oriented research program which has produced a large data base of information on equipment and system operating, maintenance, and testing. A review of the NRC Inspection Program and discussions with NRC inspection personnel have revealed several areas where the research results from NPAR would be valuable to the inspector. This report describes the NPAR information which can enhance inspection activities, and provides alternatives for making these pertinent research results available to the inspectors.

The emphasis of the NRC Inspection Program is on evaluating the performance of licensees by focusing on requirements and standards associated with the administrative, managerial, engineering, and operational aspects of their activities. The Inspection Program recognizes that licensees may satisfy NRC requirements differently, and therefore expresses inspection guidance in the form of performance objectives and evaluation criteria. For the resident and regional inspectors, procedures have been written covering various subjects, such as operations, maintenance, and surveillance. Some of these procedures contain guidance on aging degradation.

Associated with each NPAR study is the need to determine the role of inspection, maintenance, and monitoring in counteracting the effects of aging and service wear. The role of maintenance in managing aging is an important area where NRC emphasis has been applied. A review by the NRC of maintenance performed at several plants concluded that "Most utilities do not perform condition monitoring due to inadequate knowledge of degradation mechanisms and the relationship between measurable parameters and predicted functional capability."[2] The output from NPAR in this area could provide the needed information not only to assist the inspector in recognizing age-related concerns.

To obtain a complete delineation of the NRC inspectors' needs, presentations summarizing the results of the NPAR Program were made to the resident inspectors at three regions. Their comments, supplemented by a written questionnaire, indicated that NPAR results can be of use to the inspectors when provided in a format directed to their activities.

The types of information generated by NPAR which were found to be relevant to inspection needs include the following:

- Functional indicators - NPAR reports identify parameters which can be monitored or measured to detect aging degradation. The inspector can apply these results to enhance visual inspections (walkdowns) and to evaluate licensee programs for assuring equipment and system operability.

- Failure modes, causes, effects - Operating experience data evaluated in NPAR studies can alert the inspector to the prevalent failure mechanisms of systems and equipment. The potential for changes in failure rate with increasing age is useful in evaluating preventive maintenance.

- Stresses which cause degradation - An inspector can benefit from knowing the environmental and operational stresses which cause aging degradation.

- Maintenance recommendations - The inspector is required to evaluate the licensee's maintenance program for several different inspections, including special team inspections. The NPAR reports review current maintenance practices, summarize vendor-recommended maintenance, and make recommendations for preventive and corrective maintenance which can be used to detect and mitigate the effects of aging.

Based on the feedback from these presentations and from discussions with regional management, we concluded that NPAR report summaries and aging inspection guides for each completed component and system would be the best vehicle for providing concise, pertinent information. Each summary includes identification of aging-related problems, highlights of the operating experience, solutions to aging problems, and references likely to be available to the inspector. The aging inspection guide is a more concise document, which specifies licensee activities which should be conducted to manage the aging of a specific equipment or system. It also notes visual inspection techniques which may be useful in detecting degradation of the equipment. The summaries and guides for selected equipment are included in Appendix A and B.

1. INTRODUCTION

1.1 Background and Goals

Research conducted under the auspices of the U.S. NRC Nuclear Plant Aging Research (NPAR) Program has resulted in a large data base of component and system operating experience. This data base was used in the NPAR Program to determine susceptibility to aging, and the potential for equipment aging to impact plant safety and availability. The NPAR Program has also identified methods for detecting and mitigating aging in components and systems.

The NPAR Program's goals are to understand the processes of aging degradation in components, systems, and structures, and to assess methods for detecting and mitigating aging[1]. This hardware-oriented engineering research program uses a two-phase approach. The phase 1 studies assess the operating experiences in nuclear power plants to identify and characterize aging modes, mechanisms, and effects, and identify measurable functional parameters which could be used to detect incipient aging. The phase 2 research is an in-depth engineering study and assessment of aging detection and mitigation methods based on the testing of naturally aged equipment, a review of current maintenance practices in nuclear power plants, and a cost/benefit analysis for applying recommendations.

The typical output from a two-phase study of a component or system includes information such as:

- detailed assessment and evaluation of operating experience,
- evaluation of failure modes, causes, and effects,
- review of current maintenance and operating practices,
- summary of past and ongoing regulatory activities in the area including Notices and Bulletins, and Regulatory Guides,
- summary of industry standards, and
- evaluation of operational stresses which could lead to degradation or premature failure of equipment.

Associated with each NPAR study is the need to determine the role of inspection, maintenance, and monitoring in counteracting aging and service wear effects. The role of maintenance in managing aging is an important area that NRC has emphasized. A review by the NRC of maintenance performed at several plants concluded that "Most utilities do not perform condition monitoring due to inadequate knowledge of degradation mechanisms and the relationship between measurable parameters and predicted functional capability."[2] In addition, recent NRC team inspections that examined maintenance programs at nuclear power plants found that management does not consistently acknowledge the aging issue. Of the twenty-five inspection reports issued, eight specifically state that aging effects are not adequately addressed.

The potential exists for the NPAR Program to provide information which can support the NRC regional inspections. More specifically, one of the goals of this work is to explore the areas where NPAR results could enhance the inspector's understanding of the topic and contribute to a more effective inspection. Other goals are:

- to identify NPAR information that can help focus inspections on those components and systems vulnerable to age-related degradation, and
- to develop a method(s) for integrating research results into the inspection process.

1.2 The NPAR Program

More than fifty reports have been published via the NPAR Program. The systems and components which have been or are being studied are summarized in Table 1. As illustrated, the majority of completed NPAR work is in the component area. Recently, however, the research emphasis has been towards aging assessments of important nuclear plant systems. These studies provide information on all of the critical components within the system and their effect on the system performance. Abstracts of the document products from the NPAR Program have been compiled in NUREG-1377, "NRC Research Program on Plant Aging: Listing and Summaries of Reports Issued Through May 1, 1990."

Table 1 NPAR Information Areas
I. Published Component Studies

Phase 1 Component Reports	Components	Date
1. NUREG/CR-4156	Electric Motors	6/85
2. NUREG/CR-4234, Vol. 1	Electric Motor Operated Valves	7/85
3. NUREG/CR-4257, Vol. 1	In-Containment Cables	8/85
4. NUREG/CR-4302, Vol. 1	Check Valves	12/85
5. NUREG/CR-4279	Pipe Snubbers	2/86
6. NUREG/CR-4564	Battery Chargers and Inverters	6/86
7. NUREG/CR-4597, Vols 1&2	Auxiliary Feedwater Pumps	7/86,6/88
8. NUREG/CR-4257, Vol. 2	Pressure Transmitters	8/86
9. PNL-5722	ECCS Pump Room Coolers	10/86
10. NUREG/CR-4819, Vol. 1	Solenoid Operated Valves	3/87
11. NUREG/CR-4715	Circuit Breakers and Relays	6/87
12. NUREG/CR-4928	Temperature Sensors	6/87
13. NUREG/CR-4457	Batteries	7/87
14. NUREG/CR-4590 Vols. 1&2	Emergency Diesel Generators	8/87
15. NUREG/CR-4985	Reactor Coolant Pump Seals	8/87
16. NUREG/CR-4992	Multistage Switches	9/87
17. NUREG/CR-4692	PORVs and Block Valves	10/87
18. NUREG/CR-5053	Motor Control Centers	7/88

Table 1 (Cont'd)

Phase 2 Component Reports	Component	Published Date
1. NUREG/CR-4939, 3 Vols.	Electric Motors	11/87
2. NUREG/CR-5051	Battery Chargers & Inverters	8/88

II. On-Going or Planned Component Phase 2 Studies

1. Emergency Diesel Generators
2. Circuit Breakers and Relays
3. Auxiliary Feedwater Pumps
4. Check Valves
5. Snubbers
6. Solenoid Operated Valves

III. Published System Studies

Plant System Reports		System	Published Date
1.	NUREG/CR-4740	Reactor Protection	1/88
2.	NUREG/CR-5052	Component Cooling Water (PWRs)	7/88
3.	NUREG/CR-5268	Residual Heat Removal (BWRs)	6/89
4.	NUREG/CR-4967	High Pressure Injection Systems (PWR)	8/89
5.	NUREG/CR-5379, Vol.1	Service Water System	6/89
6.	NUREG/CR-5419	Instrument Air	1/90
7.	NUREG/CR-5181	Class 1E Electrical Distribution	5/90

IV. On-Going or Planned System Studies

1. Component Cooling Water-Phase 2
2. Control Rod Drive-Phase 1
3. Reactor Core Isolation Cooling(RCIC)-Phase 1
4. Containment Cooling-Phase 1

1.3 Strategy

Several tasks have been accomplished towards integrating NPAR information into the NRC Inspection Program. These tasks determined which NPAR information is relevant to the inspector, how the Inspection Program addresses the performance of components and systems, and the format in which the NPAR information can be presented so that it can be readily accessed and updated.

As illustrated in Table 2, the information flow path includes the following:

1. Determine how the NRC Inspection Program addresses the aging issue.

2. Determine the information needs of the NRC Inspection Program for effective evaluation of licensee programs.

3. Develop a format for summarizing NPAR results that are pertinent to inspections.

4. Apply the format to NPAR components and systems to access the available information.

5. Assess methods to transfer information to the regions.

Table 2 Research Strategy and Report Outline

RESEARCH APPROACH	REQUIRED ACTIVITIES
Review the NRC Inspection Program	Determine the way that the Inspection Program addresses aging
Obtain pertinent information from selected NPAR reports	Develop a format for summarizing the NPAR results that apply to NRC inspections
	Apply guidelines to two NPAR components which have completed the 2-phase research strategy
Obtain feedback from the regions on their information needs and methods of transferring the information	Present the information to the regions Conduct a survey of the inspectors Validate conclusions at selected plants
Develop recommendations	Evaluate the feedback from the inspectors, the needs of the Inspection Program, and the available resources

2. INSPECTION GUIDANCE TO ADDRESS NUCLEAR POWER PLANT AGING

Chapter 2515 of the current NRC Inspection Manual was reviewed to determine the areas of emphasis, and to ascertain where aging information could improve the inspection goals. The NRC, through the regional offices, makes independent inspections of equipment, systems, and human performance, as well as audits of each plant's inspection program and results. If necessary, augmented inspection teams are sent to a plant to resolve special issues and problems.

The emphasis of the NRC Inspection Program is on evaluating the performance of licensees by focusing on the requirements and standards associated with administrative, managerial, engineering, and operational aspects of licensee activities. The Program recognizes that licensees may satisfy NRC requirements differently, and therefore, expresses inspection guidance in the form of performance objectives and evaluation criteria[3]. For the resident and regional inspectors, there are written procedures covering various areas. Some of these procedures contain guidance related to aging degradation. Team inspections are becoming an integral part of licensee evaluations. Several types of team inspections and several procedures for resident inspector are described in this report, with emphasis on how aging effects are addressed in the inspection guidance. For the most part, this guidance is general. Specific details provided by the results from the NPAR Program could enhance this guidance substantially.

The three major areas covered by the procedures for the resident inspectors are plant operation, maintenance, and surveillance. The inspection modules which cover these areas and their relationship with plant aging are briefly described. Illustration of the aging/inspection relationship is emphasized for Plant Operations, but applies as well to Maintenance and Surveillance.

Operational Safety Verification[4]

The overall objectives of Inspection Procedure 71701 are to observe licensee activities and the status of the safety systems to ensure that the facility is being operated safely and in conformance with regulatory requirements.

The procedure indirectly addresses the aging issue by providing guidance for the inspector on equipment degradation that should be assessed. For instance, one of the weekly inspection items is to "....visually inspect the major components for leakage, proper lubrication, cooling water supply and any general condition that might prevent fulfillment of their functional requirements." Since one of the goals of NPAR is to identify functional indicators for detecting component and system degradation, more specific guidance may be useful to the inspector in determining the operational readiness of the major components inspected.

Some activities recommended in this inspection procedure (i.e., checking for fire hazards) require access to the interior of electrical panels and breaker cabinets. The inspector is directed to be aware of cleanliness and signs of overheating. Several NPAR reports have noted that overheating of the internal panel is a significant cause of age-related degradation in electrical equipment. Particular components susceptible to this type of aging include relays, inverters, battery chargers, and reactor protection system logic cabinets. A knowledge of these facts could substantially help the inspector during inspection activities.

Engineered Safety Feature System Walkdown[5]

Inspection Procedure 71710 associated with Plant Operations aims to independently verify the status of engineered safety feature systems.

The inspector is directed to "....inspect the interior of breakers and electrical or instrumentation cabinets for debris, loose material, jumpers, and evidence of rodents." The guidance provided is that the inspector should assess the overall conditions during the walkdown to identify problems which could impact the performance of the system.

This procedure addresses aging to a certain degree in that one requirement (Section 0.2.01c) directs the inspector to verify that electrical components are free from signs of overheating and all solder joints should be shiny, indicating that there is no oxidation.

If the system being inspected was reviewed in the NPAR Program, considerable background information would be available to the inspector. As shown in the flow chart in Figure 1, NPAR research results, along with other plant-specific and regulatory information, could be used to plan and prepare for an inspection. The NPAR results of interest are data on operating experience on the system, which include dominant failure modes, mechanisms, and effects. The age-susceptible stresses which contribute most to component and system degradation would also be identified, and would be useful for selecting inspection areas.

If deficiencies are observed, the NPAR research results could assist the inspector in developing the technical basis for requiring licensee action. This assistance may be in the area of methods and techniques for determining aging degradation, vendor-related information, or operational practices which have been shown to contribute factors to system unavailability. Likewise, the corrective action proposed or implemented by the licensee could be evaluated using the maintenance recommendations and evaluations from phase 2 of the NPAR studies.

Maintenance Inspections[6,7,8,9]

The monthly maintenance observation, Inspection Procedure 62703, is performed at all plants to verify that maintenance activities for safety related systems and components are being conducted properly. This procedure states that industry codes and standards should be used by the inspector to evaluate a licensee's performance. Since the codes, standards, and guides are being written and revised to reflect aging in components and systems as it impacts equipment qualification, plant life extension, and good maintenance practices, this NRC inspection procedure indirectly addresses plant aging.

NPAR research results include an evaluation of existing codes and standards for the component or system and could, therefore, be used by the inspector as a reference. Other NPAR research results which could provide an input to maintenance inspection procedures are:

1. NPAR research evaluates the vendor's maintenance recommendations and would assist the inspector in satisfying inspection requirement 02.02d of Inspection Procedure 62700.

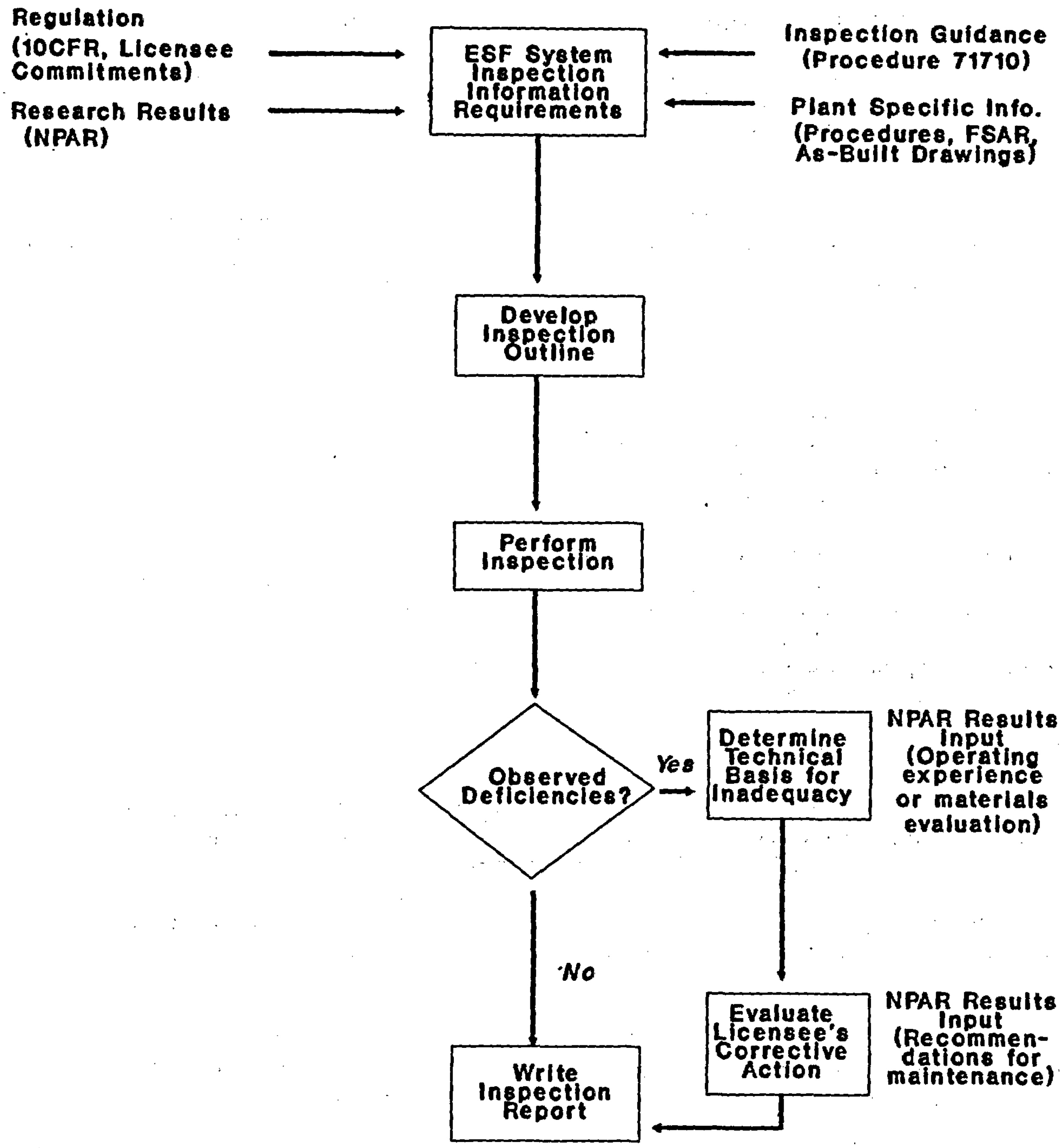


Figure 1 NPAR Input to ESF System Inspection

2. Current utility maintenance practices are reviewed in phase 2 NPAR work. This information, along with the recommendations resulting from this review, would give the inspector a reference point from which to evaluate maintenance practices as identified in requirement 02.03d of Inspection Procedure 62702.

3. Requirement 03.06 of Inspection Procedure 62702 discusses the specific attributes of motor-operated valves (MOVs) which should be inspected. A comprehensive study (NUREG/CR-4234) of MOVs was completed in the NPAR Program which gives background information on the suggested areas of inspection.

4. Inspection requirement 02.05a of Inspection Procedure 62704 addresses replacement or life extension practices for equipment which has a limited service life. This area is the core of the NPAR program. The inspector is directed to assure that the basis for extension is logical and correct. The condition monitoring practices recommended by NPAR could be used by the inspector to make this judgement.

Surveillance Inspections[10]

The objective of this inspection area (61700 series of procedures) is to ascertain whether surveillance of safety related systems and components is conducted in accordance with the technical specifications. For the most part, the inspection requirements list activities which do not require external sources of information, such as NPAR results. The possible exceptions to this are associated with the inservice inspection and inservice testing programs for pumps and valves and some of the complex surveillances to be reviewed, such as the inspection requirement for the emergency diesel generator (02.01b of Inspection Procedure 61701).

Safety System Functional Inspection (SSFI)[11]

Several team inspections are effectively used by the NRC to identify problems regarding the operational readiness of safety systems. Such inspections provide an in-depth assessment of the licensee's performance by obtaining inspection input on issues in several different functional areas. The NRC SSFI inspections have identified significant problems in plant design and hardware, such as those associated with motor-operated valves and check valves. For older plants, the SSFI inspections noted that system design documentation is incomplete.

The objective of the SSFI is to assess the operational readiness of a selected safety system by reviewing the following system areas:

- design basis requirements
- system design as installed
- maintenance and test records
- abnormal, emergency, and normal operating, maintenance, and surveillance procedures.
- operational experience

The inspection results provide the NRC with a detailed cross-section of the licensee's performance in the areas of engineering, management, operation, maintenance, training, and testing.

The NPAR research results could be a valuable resource for this detailed inspection. For example, the SSFI Procedure 93803 states that the inspector should be aware of the stresses imposed on the system during all modes of operation, i.e., the differential pressure across valves, and the pump suction and discharge pressure experienced during accident conditions. An evaluation of operational and environmental stressors is included in an NPAR system study, which could give the inspector insights into areas where there may be design weaknesses.

The SSFI guidance document directs the inspection team to determine the adequacy of the licensee's preventive maintenance program for the system. Appropriate vendor manuals are to be consulted. At both the system and component levels, NPAR results contain the practices generally employed by the industry, especially those necessary to detect and mitigate the effects of aging.

Because the NPAR program extensively used operating experience data such as LERs, NPRDS, NPE, and IPRDS, a substantial data bank was developed for systems and components. Important information on failure causes and effects are available, as well as on changes in failure rate with time for some components and systems. Risk assessments being developed to factor testing and maintenance into the aging models used in the NPAR program will assist the inspector in determining the significance of any deficiencies.

Safety System Outage Modifications Inspection (SSOMI)[12]

The SSOMI program was developed by the NRC in 1985 because of the staff's concern about the number of safety problems at operating plants which resulted from inadequate design, installation, and testing of modifications made during outages. The program initially targeted older nuclear power plants where modifications were made to upgrade equipment or to mitigate aging effects.

While aging is not directly addressed in the SSOMI inspection guidance, the system's performance is reviewed, as well as the changes made to assure the operational integrity of the system. The NPAR results include details of system design bases and operating experience which could provide valuable input to this inspection. Some modifications are made because of aging-related wear in the component or system. In these cases, NPAR insights could be effectively used by the inspector to evaluate the technical basis of the modification.

SUMMARY

To illustrate where this NPAR information may be used, a matrix (Table 3) was developed, which shows the primary categories of information applicable to the sample of inspection areas reviewed. However, we note that the inspection procedures give the inspector a great deal of latitude to perform the responsibilities. For any given inspection or inspector, the level of detail required may differ depending upon the specific circumstances. Therefore, we recommend that as much potentially useful information as possible be made available.

Table 3 Use of NPAR Results in Inspection

NPAR INFORMATION CATEGORIES				
Inspection Type (Procedure)	Background Information	Operating Exerience	Maintenance Recommendation	References
Safety System Functional Inspection (SSFI)	X	X	X	X
Safety System Outage Modification Inspection (SSOMI)	X	X		
Operational Safety Verification (71707)	X[b]	X	X[a]	X
Engineered Safety Features System Walkdown (71710)	X[b]	X[c]	X[d]	X
Maintenance Inspection (62700 Series)			X[d]	X[e]
Surveillance Inspections (61700 Series)	X[f]		X[d]	

a - NPAR functional indicators
b - Age susceptible components & stresses
c - Dominant failure modes & mechanisms
d - Evaluation of current maintenance practices
e - Industry standards & guides for various components
f - Stresses associated with testing

3. NPAR INFORMATION WITH INSPECTION APPLICATION

The review of the NRC Inspection Program revealed several areas where NPAR information could be helpful to the inspector. To obtain the desired information from the NPAR reports uniformly, and to present the results in discrete categories to the inspectors, four headings of information were defined.

a) Component background

Included under the category of component background are items such as identification of materials and subcomponents susceptible to aging, design specifications and qualifications, and operating stresses which have effects on the aging of equipment.

b) Operating experience

An important aspect of every NPAR study of components and systems is the assessment of actual operating experience to determine age-related failure modes, causes, and effects. The operating and environmental stresses are included in this section, with a discussion of problem areas in design, installation, and testing.

c) Recommendations

Recommendations encompass the major research results including functional indicators and viable techniques for aging detection and mitigation. Also included is an evaluation of current maintenance practices, vendor recommendations, and the results of any testing performed as part of the research.

d) References

The fourth category of information that can be applied to inspection activities are selected report references, such as NRC documents associated with the equipment, as well as related industry standards.

A detailed breakdown of these four information categories are listed below.

3.1 Component background information

a. **Boundary:** The interface limits of the component are defined; i.e., inverter includes input breaker to output breaker.

b. **Related Systems (where used):** The major systems where the component is used are indicated.

c. **Types and Sizes:** The types and sizes of the component included in the study are listed.

d. **Function:** A description of the safety-related function of the component is provided.

e. **Age-Dominant Materials:** The materials most susceptible to aging are listed.

f. **Designs and Configurations:** The component designs are reviewed, and any alignment differences are noted.

g. **Subcomponents:** The subcomponents most susceptible to aging are listed.

h. **Subcomponent History:** For the subcomponents identified above, any significant age related information is provided including:

- application to other equipment or systems
- estimates of service life
- design parameters and specifications

i. **Specifications:** The typical specifications associated with this equipment are given, including electrical, mechanical, and environmental parameters.

j. **Operating/Accident Parameters:** The most limiting operating and accident conditions affecting this equipment are given.

k. **Manufacturers:** The major manufacturers and suppliers of this equipment are listed.

3.2 Operating Experience

a. Summary of failure data is given.

1. **Number of Failures:** Summarizes the operating experience for the component based on LERs, NPRDS, and NPE giving the period reviewed.
2. **Subcomponents Failed:** Lists the number of failures attributed to subcomponents.
3. **Failure Causes:** Lists the causes of failure identified and the number of failures.
4. **Failure Effects:** Lists the effects of failure identified and the number of failures.

b. **Design-Related Problems:** Any design and manufacturing errors which have contributed to component aging are given.

c. **Environmentally Related Failures:** Describes any age-related failures which were due to environmental conditions.

d. **Operational stresses:** Describes the operational stresses which contribute most to the aging of the component.

e. **Change in Risk Impact With Age:** Provides the relationship of a time-dependent change in failure rate with a change in system unavailability, plant risk, or plant unavailability.

f. **Human Factors:** Summarizes the failures associated with errors in operations or maintenance.

g. **Testing:** Summarizes the failures associated with equipment or system testing.

h. **Installation:** Lists installation errors which resulted in premature failures of components.

3.3 Recommended Maintenance, Testing, and Inspection

a. **Functional Indicators:** Describes the parameters which can be monitored periodically or continuously to determine the component's health.

b. **Age Mitigation Techniques:** Describes the practices for detecting or mitigating the effects of aging on this component. Indicates frequency of performance, where applicable.

c. **Vendor Recommendations:** Lists the specific vendor recommendations for this component, and identifies the source of the recommendation, i.e., technical bulletin.

d. **Storage Recommendations:** Lists the storage requirements for the component and cites the source of the requirement, i.e., ANSI standard.

e. **Recommended Maintenance Practices:** Summarizes the NPAR report's recommendations on preventive maintenance. The technical basis for each recommendation is given.

f. **Corrective Maintenance Methods:** Summarizes important repair practices which should be employed to reduce age-related failures.

g. **Trending Techniques:** Suggests component trends which could be monitored to detect age-related degradation.

h. **Results of Testing Performed:** Describes the results of any testing performed on naturally or artificially aged equipment which revealed aging degradation.

i. **Important Inspection Concerns:** Lists the inspection areas which provide the most valuable feedback to the NRC inspector on the component's operational readiness.

3.4 References

a. **Bulletins, Notices, Regulatory Guides:** Lists the NRC documents associated with the component.

b. **Reports, AEOD Case Studies:** The reports associated with this component which could be useful to the NRC inspector are listed.

c. **Related Industry Standards such as IEEE, ASME:** Summarizes industry activities associated with the aging of this component, such as equipment qualification, and plant life extension.

3.5 Feedback From Regions

The NPAR results and their potential use was presented to inspectors at Regions 1, 2, and 3. The major segment of the presentation provided specific examples of NPAR research results and how they could be applied to inspection activities. Excerpts from the NPAR reports were arranged in four categories-component background, operating experience, recommendations, and references.

A survey form was given to the inspectors, whose purpose was to:

a. rank the four types of NPAR information;

b. identify components and systems for which information is desired;

c. rank the proposed means for transmitting NPAR information;

d. determine which plants have programs which address aging, and

e. solicit comments on the overall program of applying aging research results to the inspection process.

As illustrated in Figures 2 and 3, this feedback indicated that:

1. The NPAR results are potentially useful to the inspectors, with most people desiring information on operating experience (60% said this would be very useful.)

2. Most inspectors felt that summaries of the NUREG/CR results would be the best method of alerting inspectors to NPAR results, followed closely by performing inspections focused on aging issues. While there was a mixed reaction from the Region 3 resident inspectors on the usefulness of revising the NRC Inspection Program to include guidance on aging, Region 1 inspectors felt that including NPAR results as appendices to the inspection procedures could be useful. They added that this may not be as valuable to the resident inspectors because they may not consult the procedures as often as the regional inspectors.

3. The respondents listed many systems and components which were of interest to them from the perspective of aging. There was only minor commonality indicating that information needs vary widely depending on the individual's experience, and the problems at the plants to which they are assigned. For instance, in Region 3 where 17 inspectors responded to the survey, those components for which information was desired by at least three inspectors were: cable (5), diesel generators and chargers/inverters (4), relays, motors, and batteries (3); The systems identified were service water (4) and component cooling water (3); The components and systems listed which are not presently covered by NPAR were power supplies, nuclear instrumentation, air operated valves, radiation monitors, the automatic depressurization system, and the recirculation system (BWRs).

4. Only a small percentage (<10%) of the inspectors were aware of any actions being undertaken by the utilities to address the aging issue.

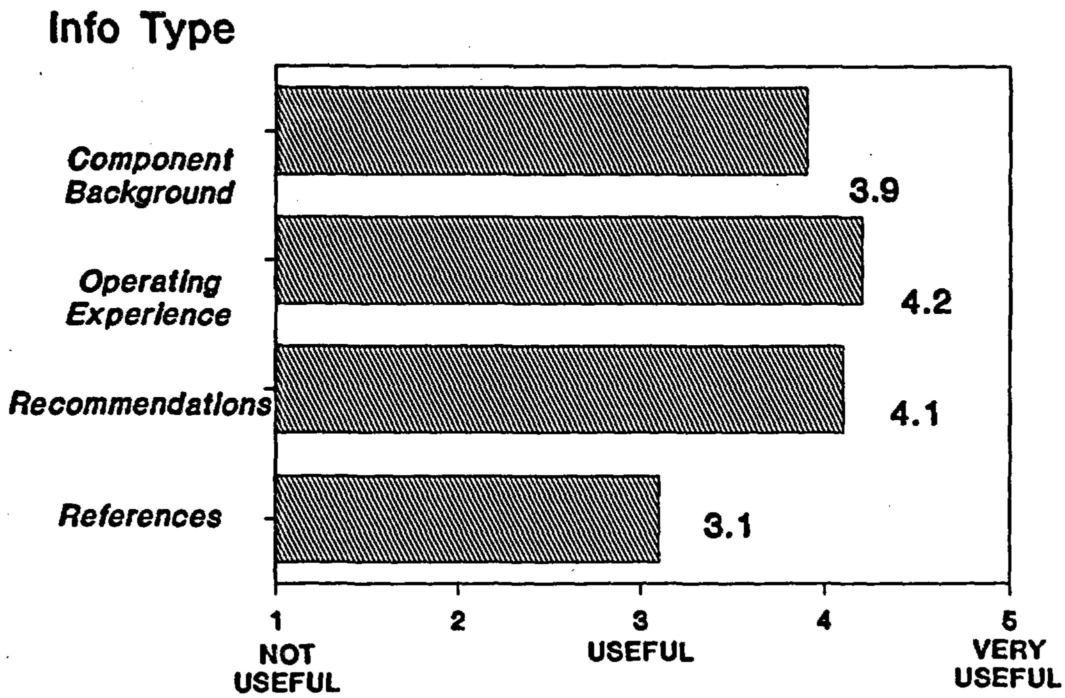


Figure 2 NPAR Information Desired by Inspectors

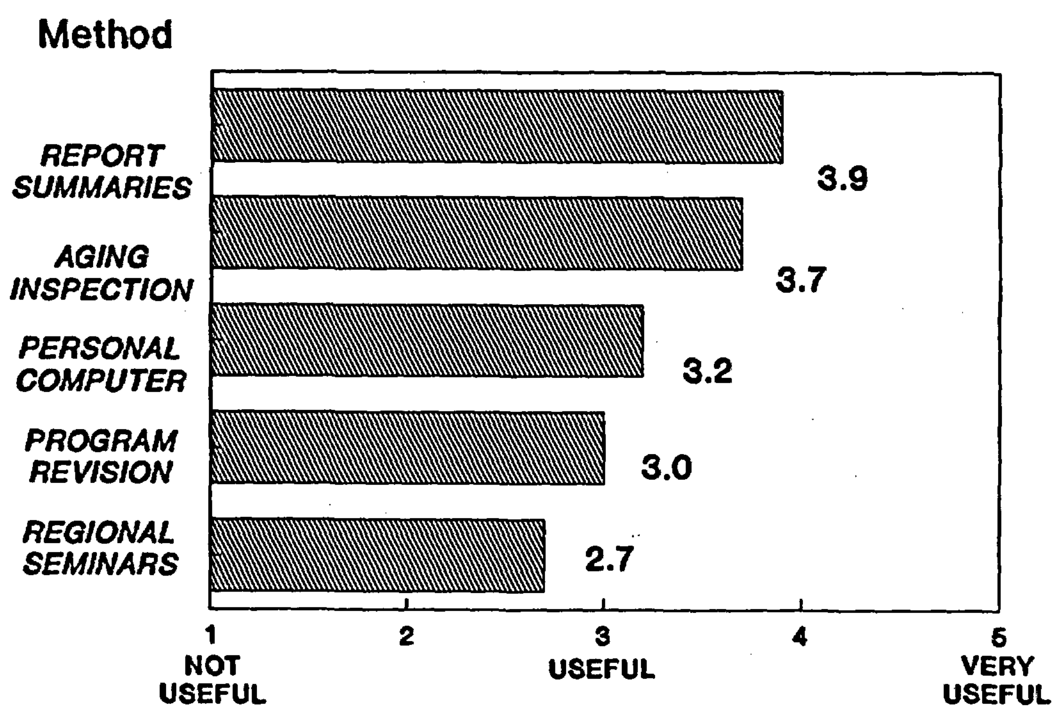


Figure 3 Preference for Method of Information Transfer

3.6 Other NRC Input

To support the NRC's team inspections of maintenance programs at nuclear power plants, a two-volume Maintenance Inspection Guidance was published in September 1988. As part of the inspection checklist, the team is expected to evaluate the extent to which management is aware of plant aging. Of the first twenty five reports issued on the team inspections, eight (32%) found that utility management was not aware of the aging issue, specifically making the following points:

- "No program in place to address plant aging effects."
- "Lack of management attention to aging."
- "No followup to aging failures."

Several inspectors at the regional seminars felt that the utilities must develop programs to address the aging issue before the inspectors could use NPAR results effectively. Basically, they felt that the NPAR reports provided inadequate regulatory support for the inspector to obtain corrective action from the licensees. The need for NPAR results to be moved into the regulatory area, should be pursued further. In addition, it is apparent that there is a need for utilities to develop programs to address the aging issue.

4. APPLICATION OF NPAR RESULTS TO INSPECTION ACTIVITIES

Supported by the feedback obtained from the inspectors, NPAR reports for selected components and systems were reviewed, and information was extracted that could be of use to inspection activities. This information was compiled into two documents called an aging report summary and an aging inspection guide.

The aging report summary, of approximately 1500 words, has the following format.

a) Summary of Results - This is a brief overview of the study which addresses the question of whether or not aging is a significant safety concern for the particular component or system.

b) NPAR Reports - This is the reference NUREG report number which provides the basis for this summary.

c) Aging-Related Problems - This section briefly describes the components most susceptible to aging, the stresses which affect service life, and the dominant causes of failure.

d) Operating Experience - The failure history of the component or system is discussed. This operating experience is typically based on the LER or NPRDS data bases, but could include specific plant data. Significant causes and effects of failure are highlighted.

e) Solutions to Aging Problems - The largest portion of the summary is devoted to the recommendations presented in the NPAR reports for detecting and mitigating aging effects. Periodic testing, maintenance, continuous monitoring, and routine inspections are some of the techniques described for the specific equipment or system.

f) References - The summary contains references to the NRC documents and industry standards that are available to the inspector. The NRC documents include AEOD reports, information notices, and regulatory guides associated with the equipment, while industry documents include ASME, IEEE, ISA, and NEMA standards and guides.

The aging inspection guide is a concise document focused on the specific inspection activities to be considered when assessing the operational readiness of the component or system. The guide contains visual-inspection techniques for detecting aging degradation, including external and internal indicators, and important operating parameters. In addition, the guide lists those activities associated with maintenance, operations, design, and testing which the licensee should employ to demonstrate that aging is understood and is being adequately managed.

Appendix A contains the sample report summaries for several studies of components and systems, completed as part of the NPAR program. The components addressed are the inverter, battery charger, motor, and motor control center. The systems included are Component Cooling Water (PWRs) and Residual Heat Removal (BWRs). It should be noted that the system summaries are based on phase 1 work only and could be modified following the phase 2 efforts. Appendix B contains the aging inspection guides for the same components and systems.

5. INFORMATION TRANSFER

Several alternative methods for transferring NPAR results to the regions were presented to the inspectors for their comment.

- Manual of NPAR Results
- Conduct On-Site Inspections
- Personal Computer
- Revision of the NRC Inspection Manual
- Presentation of NPAR Results at Regional Meetings

5.1 Manual of NPAR Results

It was clear from the survey response that a hard copy of the information is desired, as long as it is concise and directed towards the inspector's activities. This method has been pursued and is recommended as the primary method of information transfer. Report summaries and aging inspection guides for other NPAR components and systems can be completed and organized in a manual that can be updated as work is completed. A possible layout of a document is depicted in Table 4.

5.2 Conduct On-Site Inspections

Success was achieved using a team inspection approach (from the regions or headquarters) to assess the performance of utilities in the areas of maintenance, fire protection, equipment qualification, and system design, among others. A similar approach could be taken to assess a plant's ability to detect and mitigate aging. Because few plants have a formal program to address equipment aging, the inspection team would most likely focus on maintenance practices, routine operator activities, and procedures to evaluate test data. The inspection team would be composed of personnel familiar with these areas and cognizant of NPAR findings and recommendations.

The disadvantage of on-site inspections is the possible duplication of effort resulting from a separate NPAR inspection. It is more likely that NPAR information can support maintenance, operations, and routine inspections by the resident inspector, rather than warranting a comprehensive team inspection. Therefore, it is not recommended as a primary method of transferring NPAR information to the regions. It can be used, however, on an as needed basis for a special inspection where it is expected that insufficient attention is being devoted to the aging issue.

Table 4 Manual of NPAR Results

GOAL:

Combine the results from related NUREGs into a single document on aging, emphasizing inspection.

A. Electrical Systems/Components

- Circuit Breakers/Relays
- Batteries
- Chargers/Inverters
- Electric Penetrations
- MCCs
- Cables
- Motors
- Connectors
- Diesel Generators
- Transformers
- Motor Operated Valves
- Solenoid Operated Valves
- Switches

B. ECCS Systems/Components

- HPCI
- RHR
- HPSI (PWR)
- Control Rod Drive
- Auxiliary Feedwater
- PORVs
- Heat Exchangers
- Check Valves
- Snubbers

C. Support Systems

- CCW
- Service Water
- Instrument Air
- Room Coolers
- RCP Seals
- BOP Systems

D. Instrumentation and Controls

- RPS
- Sensors/Transmitters
- Bistables/Switches
- Power Supplies

A team inspection plan to evaluate licensee programs to determine that operations, maintenance, and testing adequately address the effects of equipment and system aging should review the following areas:

1. Corrective maintenance records of age susceptible equipment to determine rates of failure and evidence of recurring failures.

2. Preventive maintenance program to determine content and frequency of PM, and changes in the program to reflect actual or anticipated increased failure rates.

3. Operating procedures to determine that precautions are taken to minimize operational stresses.

4. Operating logs to determine if operating stresses are identified, i.e., area temperatures, unusual noise or vibration, oil or water leakage.

5 Maintenance procedures to determine if "as found" conditions are identified, if spare parts controls are in place, and if there is root-cause evaluation of detected wear.

6. Equipment status to determine its condition.

7. Document controls to determine that vendor's recommendations are incorporated in maintenance procedures and are maintained current.

An inspection of this type would provide reasonable assurance that the licensee's programs effectively consider those aspects of plant aging that affect plant safety.

5.3 Personal Computers

With the expanding use of personal computers at NRC offices, and the desire to minimize the paper routinely processed by NRC inspectors, exploring the application of NRC information resources such as the Safety Information network (SINET) or the Safety Issues Management System (SIMS) should be considered.

The purpose behind the SINET initiative is to collect information related to NRC licensees and their operations into a centralized data base, to which both headquarters and regional staff would have access.

The overall purpose of SIMS is to provide NRC staff with an effective system to manage information to assure the timely resolution of outstanding concerns, including the aging issue.[13]

5.4 Revision of the NRC Inspection Manual

The NRC Inspection Program consists of procedures that provide instructions and guidance for the resident inspector, team inspections, vendor evaluations, and inspections for equipment qualification.

Based on the review of the Inspection Manual, generic NPAR recommendations could be incorporated through a revision of the Manual. Samples of the report summaries and aging inspection guides were submitted to the NRC's Inspection and Licensing (ILPB) Program Branch for their information. Several mechanisms, including temporary instructions, are available through ILPB to distribute information and guidance to the regions.

5.5 Presentation of NPAR Results at Regional Meetings

A practical alternative to disseminate NPAR information is to present the results directly to the inspectors.

Presentations by NRC staff and national laboratory NPAR representatives were made to each of the Regions over the past two years. These presentations provided regional and resident inspection personnel with an overview of the NPAR Program and its results. It is conceivable that NPAR results could continue to be disseminated through this type of meeting. To achieve maximum advantage, a workshop atmosphere is recommended that would permit a free exchange of information.

6. CONCLUSIONS AND RECOMMENDATIONS

The Nuclear Plant Aging Research Program has the potential to support the ongoing inspection effort conducted by the regions in accordance with the NRC Inspection Program. One objective of the inspection effort is to ensure that systems and components have not been measurably degraded as a result of any cause, including aging. The following objectives coincide with this goal as stated in the NPAR Program Plan:

1. Identify aging effects which could cause component or system degradation and impair plant safety.

2. Identify methods of inspection, surveillance, and monitoring to detect aging effects before the loss of safety function.

3. Evaluate the effectiveness of storage and maintenance practices in mitigating aging effects.

To achieve the NPAR Program objectives, research results have included such important inspection attributes as:

1. Compilation of component and system operating experience data.

2. Identification of component and system failure modes, mechanisms, and effects.

3. Identification of the operating and environmental stresses contributing to failure.

4. Evaluation of current industry maintenance and testing practices.

5. Recommendations for inspection, maintenance, and monitoring practices to detect and mitigate aging in components and systems.

This report describes the effort associated with evaluating the potential of integrating the NPAR results into the NRC Inspection Program: our conclusions and recommendations are summarized in this section.

6.1 Conclusions

Based on the feedback obtained from regional and resident inspectors, it is concluded that the use of NPAR results can improve the inspection process. The inspectors are closely involved with technical issues at the plants and generally agree that equipment and system aging is an issue that should be addressed by all licensees. Therefore, they are interested in research findings and recommendations that enhance their understanding of the issue.

The review of inspection procedures suggests that the information requirements of the inspector are vast. We therefore conclude that the NPAR data base can assist the inspector in focusing their activities on those components and systems most likely to affect plant safety as the plant ages. In addition, the NPAR data and research results can provide the inspector with criteria for determining the validity of findings and the completeness of licensees' responses. Evaluating a licensee's administrative programs is another area where NPAR results can provide a reference, especially those reviews associated with operations, maintenance, and testing.

NPAR-generated information which has a direct relationship to the requirements of the NRC Inspection Program are:

- functional indicators
- failure modes, causes, and effects
- degradation causing stresses
- maintenance recommendations
- component and system risk impact as a function of time.

Examples of inspection procedures reviewed which could benefit from one or more of those NPAR results are:

- 71707, Operational Safety Verification
- 71710, Engineered Safety Feature System Walkdown
- 62700 series, Maintenance Program Inspections
- 61700 series, Surveillance Program Inspections
- Safety System Functional Inspection (SSFI)
- Safety System Outage Modification Inspection (SSOMI)

6.2 Recommendations

To achieve the goal of transferring useful information from the NPAR program to the regions we recommend:

1. Summarize the research from NPAR reports that are applicable to NRC inspection activities. A summary of the research results, coupled with an aging inspection guide will provide the inspector with important insights into the aging degradation of various equipment and systems. The summary for each equipment type and system studied in the NPAR Program would include the identification of aging-related problems, highlights of the operating experience, solutions to aging problems, and references likely to be available to the inspector. The aging inspection guide is a more concise summary of recommendations emphasizing visual inspection techniques, and activities to evaluate licensee's programs for understanding and managing aging.

2. Establish a schedule of regular regional seminars by NPAR contractors. Results oriented discussions by NPAR representatives would be of mutual benefit to the regions and NRC research. A workshop atmosphere for discussion of components or systems of particular interest to the region would be of greatest value.

3. Pursue the development of a software supported database. Continuation of work with the NRC's Data Administration Branch to make NPAR results available through a system such as the Safety Information Network (SINET). With the expanding use of personal computers at NRC offices and the desire to minimize the amount of documentation routinely processed by the NRC inspectors, exploring the application of a data base system is appropriate.

7. REFERENCES

1. NUREG-1144, Rev. 1, 9/87, "Nuclear Plant Aging Research (NPAR) Program Plan."

2. NUREG-1212, Vols. 1 & 2, "Status of Maintenance in the U.S. Nuclear Power Industry," 1985.

3. NRC Inspection Manual, "Policy and Guidance for Development of NRC Inspection Manual Programs," Chapter 0033, 10/13/87.

4. Inspection Procedure 71707, "Operational Safety Verification," 8/29/88.

5. Inspection Procedure 71710, "Engineered Safety Feature System Walkdown," 7/14/87.

6. Inspection Procedure 62700, "Maintenance Program Implementation," 2/20/87.

7. Inspection Procedure 62703, "Monthly Maintenance Observation," 2/20/87.

8. Inspection Procedure 62704, "Instrumentation Maintenance (Components & Systems) Observation of Work, Work Activities, and Review of Quality Records," 2/20/87.

9 Inspection Procedure 62705, "Electrical Maintenance (Components & Systems) Observation of Work, Work Activities, and Review of Quality Records," 2/20/87.

10. Inspection Procedure 61700, "Surveillance Procedures and Records," 9/13/83.

11. NRC Inspection Manual, "Light-Water Reactor Inspection Program-Operations Phase," Chapter 2515-Appendix D, 8/30/88.

12. Memo: J.G. Partlow to Regional Directors, "Inspection Checklists - Safety System Outage Modifications Inspection Program," 6/86, 54 pages.

13. NUREG-1145, Vol. 4, "U.S. NRC 1987 Annual Report," pps. 172-177.

APPENDIX A

NPAR REPORT SUMMARIES

AGING REPORT SUMMARY
INVERTERS

SUMMARY

Inverters are used in nuclear power plants to convert dc to ac power for instrumentation, controls, and other equipment necessary for power operation and safety. Research has shown that inverter performance will degrade with time due to the aging susceptibility of some components and materials. This degradation can be detected and mitigated through maintenance, operation, and design activities. This guide summarizes these recommended practices, and identifies areas of inspection importance.

BASED ON:

1. **NUREG/CR-4564, *Operating Experience and Aging-Seismic Assessment of Battery Chargers and Inverters***
2. **NUREG/CR-5051, *Detecting and Mitigating Battery Charger and Inverter Aging***
3. **NUREG/CR-5192, *Testing of a Naturally Aged Battery Charger and Inverter***

AGING RELATED PROBLEMS

A large percentage of inverter failures are due to hardware. Components susceptible to aging degradation are:

1. <u>FILTER CAPACITORS:</u> These components have experienced a limited service life (approximately 5 years) directly related to ambient temperature, applied voltage, and ripple current.

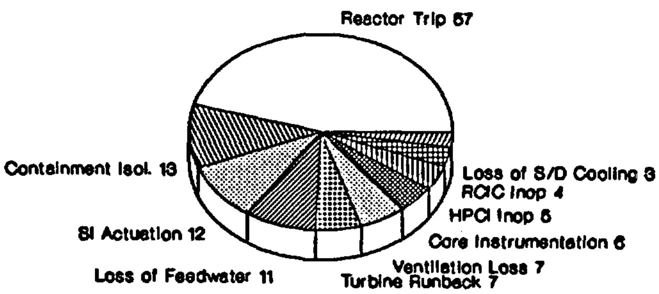
2. <u>THYRISTORS (SCRs)</u>: Large SCRs used in the power conversion circuit generate heat which is designed to be dissipated through attached heat sinks. Improper torque of the SCR/heat sink connection has resulted in overheating and failure of the SCR.

3. <u>FUSES:</u> Fast acting fuses are used to protect inverter electronics and are subject to a thermal fatigue. Depending on internal cabinet temperature and the proximity of the fuse rating to normal load current, expected life can vary from 5 to 25 years. As the fuses degrade, they are more susceptible to normal plant electrical transients such as starting motors and switching operations.

OPERATING EXPERIENCE

INVERTER FAILURE EFFECTS

Number of Events

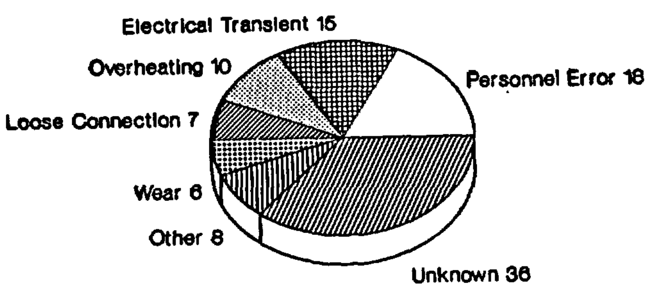


LERs 1984 - 1986

The operating experience data demonstrates that inverter failures can impact plant safety and availability. One of the most visible and dramatic effects of an inverter failure is reactor trip. From 1984 to 1986, 57 reactor trips resulted from an inverter failure. In addition, safety injection (SI) system actuations, containment isolations, and safety system (HPCI & RCIC) inoperability were directly linked to inverter failures.

INVERTER FAILURE CAUSES

Percent of Failures



LERs 1976 - 1986

The analysis of data on operating experience accumulated over 12 years indicates that overheating, electrical transients, and errors by plant personnel are the leading causes of inverter failures. Such stresses cause aging of critical components. The large percentage of unknown causes may be due to 'normal' electrical switching where inverter fuse or circuit breaker operation results.

SOLUTIONS TO AGING PROBLEMS

DESIGN

Four basic designs of inverters are used in the nuclear industry. Improvements were made in the more recently manufactured units, such as:

1. The use of an automatic transfer switch, which senses an inverter failure and switches to a backup power source without a detectable loss of power to vital equipment.
2. The installation of higher voltage and temperature rated components, especially capacitors and semiconductors. This makes these components less susceptible to operationally induced stresses.
3. Forced air cooling rather than natural convection cooled units tend to have less overheating problems. Several utilities have modified the inverters in this manner.
4. Additional monitoring capabilities, including annunciation of abnormal conditions, such as high temperature, are available in newer units.

MAINTENANCE & MONITORING

Based on the inverter's importance and the effects of its failure on plant safety and availability, a comprehensive maintenance program is recommended. To detect and mitigate the effects of aging on inverters, this program should include inspection, testing, and preventive maintenance.

(continued)

MAINTENANCE & MONITORING

INSPECTION

The inspection of an inverter by experienced personnel can provide a great deal of information about the equipment's overall condition.

1. While operating, observation of cyclical electrical hum, meter oscillation, or cooling fan noise can indicate an impending failure.
2. Component degradation due to overheating, and loose electrical and mechanical connections can be detected when the inverter is off-line.
3. Cleaning can minimize the risk of overheating. The wiping of SCR heat sinks and ventilation flow paths improves heat transfer away from temperature sensitive components.

TESTING/MONITORING

Periodic testing is necessary to verify that design parameters are obtainable under all conditions. The acceptance criteria for such testing should be based on specific plant and manufacturer information.

1. Overheating is an important cause of stress that can reduce the expected life of electrolytic capacitors, thyristors, and inductors. It is prudent to periodically monitor them to detect any increase in temperature.
2. The component's performance may change with time and can indicate degradation. Two parameters for detecting aging of electrolytic capacitors are an increase in the equivalent series resistance (ESR) or a decrease in capacitance.
3. Capacity testing is recommended, especially for standby inverters. This verifies that the inverter can supply design loads, and permits inspection monitoring techniques to be applied at rated conditions.
4. The automatic transfer switch should be tested to verify it is capable of transferring to the alternate supply without interrupting power to critical equipment.

PREVENTIVE & CORRECTIVE MAINTENANCE

Specific requirements from the manufacturer should be incorporated into the maintenance program. These are based on the manufacturer's experience or are generated as a result of equipment qualification. Guidelines are also provided to restore the inverter to an operable condition following a failure.

1. Deviations from equipment qualification requirements require documented engineering analyses. Components which have been identified as having limited service life include capacitors, cooling fans, fuses, circuit breakers, and relays.
2. Replacement power electronics, such as SCRs, should be remounted to a cleaned heat sink surface at the torque specified by the vendor.
3. Loose power cable terminal contact surfaces should be cleaned before tightening.
4. Fuses identical in rating and design should be used.

REFERENCES

These documents provide additional background information on inverters used in nuclear power plants.

1. **AEOD Case Study Report C605,** "Operational Experience Involving Losses of Electrical Inverters", 12/86.
2. **Information Notice 87-24,** "Operating Experience Involving Losses of Electrical Inverters".
3. **Information Notice 88-57,** "Potential Loss of Safe Shutdown Equipment Due to Premature SCR Failures".
4. **IEEE-650-1989,** "IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations".

AGING REPORT SUMMARY

MOTORS

SUMMARY

Motor degradation due to aging and service wear decreases reliability and increases the potential for failure. The impact of motor failures on plant safety is significant since motors play a vital role in most safety systems. The evaluation of motor performance in nuclear and non-nuclear industries and laboratory testing of aged motors has identified elements for an improved maintenance program comprised of comprehensive inspections and periodic testing of motor subcomponents.

BASED ON:

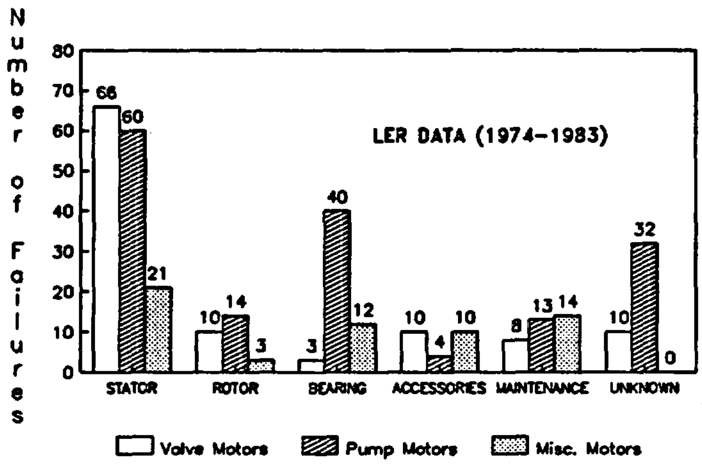
1. **NUREG/CR-4156, Operating Experience and Aging-Seismic Assessment of Electric Motors.**
2. **NUREG/CR-4939, Volumes 1,2,3; Improving Motor Reliability in Nuclear Power Plants.**

AGING RELATED PROBLEMS

For smaller motors (under 200 hp), the stator insulating system and bearing assemblies are the subcomponents that most frequently failed. The major factors contributing to large motor failures include voltage surges and mechanical stresses due to centrifugal or magnetic forces.

1. **INSULATING MATERIAL:** Insulating material is primarily degraded by heating cycles of the winding due to starting, as well as overload conditions. Humid environments produce more rapid degradation in both cases.
2. **BEARINGS:** Bearing failures are primarily caused by deterioration of lubrication or mechanical misalignment.
3. **TEMPERATURE:** Thermal effects commonly result from excessive current which imposes self-heating and results in insulation failure.
4. **VIBRATION:** Vibration can originate from internal and external abnormalities, and is often caused by coupling misalignment, rotor imbalance, and loose parts.
5. **MOISTURE**: Humidity can reduce properties of electrical insulation. High humidity promotes dirt buildup on the windings, leading to overheating.

OPERATING EXPERIENCE



Motor Component Failure Distribution

Regardless of size and system application, motors are subject to stresses which may eventually cause failure. Stator-related failures are the highest having nearly an equal probability of occurrence for both pump and valve motors. Bearing failures are significantly higher for pump motors than for valve operators.

LARGE MOTOR FAILURES CLASSIFIED BY INSULATION TYPE

INSULATION CLASS	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1982
A	-	4	13	2	4	1	1	1	-	-	-	1
B	19	19	28	13	26	20	21	53	26	29	34	42
F	3	2	4	4	2	7	8	3	13	9	7	19
H	1	-	3	2	1	1	1	1	-	4	-	1
OTHER	-	1	5	2	2	-	2	1	6	1	3	3
TOTAL	23	26	53	23	35	29	33	59	45	43	44	66
Average Service Life	4.7	-	5.7	6.2	5.7	3.6	4.3	3.2	5.1	6.1	6.2	12

Average Service Life = Average Age at Time of Failure

For 250HP motors and above, class B insulation systems, which were used in safety & non-safety applications at older plants & non-safety applications at newer plants, have experienced the most failures. Most newer plants (post 1980) use class F or H insulation for safety systems.

SOLUTIONS TO AGING PROBLEMS

A preventive maintenance program should exist for motors important to plant safety and availability. To evaluate the performance of a motor, the PM program should include periodic testing, continuous monitoring, and inspection techniques.

PERIODIC TESTING

Periodic tests are in situ tests performed in the plant on the equipment at scheduled intervals to detect degradation and verify operability.

1. Insulation resistance (megger) tests are go/no go tests that are effective for the post maintenance check of a motor. They indicate the dryness of the insulation but are not useful for predicting overall insulation dielectric conditions.
2. A partial discharge test is used for large motors with a voltage rating above 500 volts, and can provide results which are useful for trending. It detects void growth and corona discharge in the insulation by measuring the discharge inception voltage, which decreases as the insulating material gets older.
3. Power factor or dissipation factor testing is used on high voltage motors and is suitable for monitoring average insulation condition.
4. During technical specification testing of pumps and valves, motor running current and bearing vibration should be measured and recorded. Where available, the winding and bearing temperatures should also be measured and trended.
5. Ac and dc leakage tests (hipot) have proven to be effective in locating faults, however, they have several shortcomings including the imposition of electrical stress. If used, it is recommended that the voltages be applied in small discrete steps up to the test voltage.

SOLUTION TO AGING PROBLEMS
(continued)

6. Voltage impulse or surge testing can detect turn shorts or hot spots in the insulating material in low voltage motors.
7. The chemical analysis of the lube oil will indicate excessive bearing wear or contamination within the lubricating system.

CONTINUOUS MONITORING

Motors equipped with permanently installed devices should be monitored regularly. A baseline value should be developed for each parameter. Readings should be evaluated by comparison to baseline readings.

1. Parameters typically monitored are line/phase current or voltage, winding and bearing temperatures, lube oil temperature, and bearing vibration signals.

2. Guidelines for the frequency of evaluating continuously monitored parameters for safety related motors are:

   a. Line/phase current: 6 to 12 months
   b. Winding temperature: 3 to 6 months
   c. Bearing temperature: 1 to 3 months
   d. Lube oil temperature: 3 to 6 months
   e. Bearing vibration: 1 to 3 months

3. Bearing temperature and vibration measurements are proven methods for indicating degradation in bearing assemblies. A high temperature or vibration is a clear indication of bearing wear, misalignment, or other aging mechanisms.

SOLUTION TO AGING PROBLEMS
(continued)

INSPECTION

Motors, regardless of their sizes and types, should have a periodic inspection to evaluate their condition. The inspection program assures the operational readiness of of motors between scheduled testing or maintenance.

10 POINT INSPECTION PROGRAM FOR MOTORS

GUARD AGAINST

1 → DIRT, DUST, & CONTAMINANTS
2 → MOISTURE, WATER, GREASE & OIL
3 → FRICTION
4 → VIBRATION/MOUNTINGS
5 → EXTREME ENVIORNMENTAL CONDITIONS
6 → CRACKS/CORROSION
7 → ELECTRICAL STRESSES
8 → AGE AND SERVICE WEAR
9 → HUMAN ERROR
10 → LOSS OF INSPECTION DATA

1. Dirt, dust, and contaminants may be removed by wiping the motor clean with a dry cloth. Regulated compressed air can be used to reach inaccessible areas.

2. Moisture intrusion into motor components significantly increases the probability of failures. Space heaters should be used to thoroughly dry the motor before it is returned to service.

3. Excessive belt tension, poor alignment, a bent shaft, excessive end bell thrust, or damaged bearings can result in friction and high noise levels.

INSPECTION
(continued)

4. Winding vibration can be caused by loose rotor bars or end rings, phase imbalance, or improper lubrication.

5. Humidity, temperature, radiation, and chemical spray can effect the motor's service life. When required to operate in post-accident conditions, the motor should be shielded as much as possible from potential severe environmental stresses.

6. Surface corrosion or cracks on the motor's components can be detected by a thorough visual inspection. High frequency vibration can initiate cracks or voids at high stress regions.

7. A good visual inspection of insulation surfaces for corona discharge (white and grey deposits) or burn marks can detect a degrading insulation.

8. Some components have a finite life because of their age and service wear, such as seals, bearings, gaskets, and carbon brushes. A typical life for bearings in small motors is ten years.

9. An inspection checklist performed by trained maintenance personnel can help eliminate many of the problems introduced by the human.

10. Logging the inspection activities and observations of motor conditions can provide insight into the motor's performance.

REFERENCES

The universal applications of electric motors has resulted in a multitude of references. The following list reflects those which may be more accessible to the inspector.

1. IEEE Std. 334-1974, Type Test of Continuous Duty Class 1E Motors for Nuclear Power Generating Stations.

2. IEEE Std. 432-1976, Guide for Insulation Maintenance for Rotating Electrical Machinery.

3. EPRI NP-3416, A Guide for Developing Preventive Maintenance Programs in Electric Power Plants.

4. EPRI NP-3887, Life Expectancy of Motors in Mild Nuclear Plant Environments.

5. Information Notice 88-12, Overgreasing of Electric Motor Bearings.

AGING REPORT SUMMARY
BATTERY CHARGERS

SUMMARY

Battery chargers convert ac to dc to provide power to dc driven equipment and components, as well as to maintain the standby battery fully charged. The battery charger components most susceptible to aging are capacitors, transformers inductors, diodes, and thyristors. High voltage, current, humidity, or temperature will decrease the life of these components. A failed or degraded battery charger which is not detected and corrected in a timely manner could result in depletion of its associated battery and a partial loss of station dc power.

BASED ON:

1. NUREG/CR-4564, *Operating Experience and Aging-Seismic Assessment of Battery Chargers and Inverters*
2. NUREG/CR-5051, *Detecting and Mitigating Battery Charger and Inverter Aging*
3. NUREG/CR-5192, *Testing of a Naturally Aged Battery Charger and Inverter*

AGING RELATED PROBLEMS

The small number of battery charger failures reported in the LER data base which were attributed to component degradation indicates that, to date, the aging impact is minimal. This may be due to adequate attention being applied at the plant level. However, the charger contains many components identical to those found in inverters, where aging is important. The potential therefore exists for future age-related failures of battery chargers, including the following failure modes:

1. **Degraded Voltage:** Failures of components within the voltage regulation circuitry can result in voltage fluctuations which affect operation of equipment supplied by dc power. Degradation of potentiometers that establish the equalize and float voltages can also have this effect.

AGING RELATED PROBLEMS
(CONTINUED)

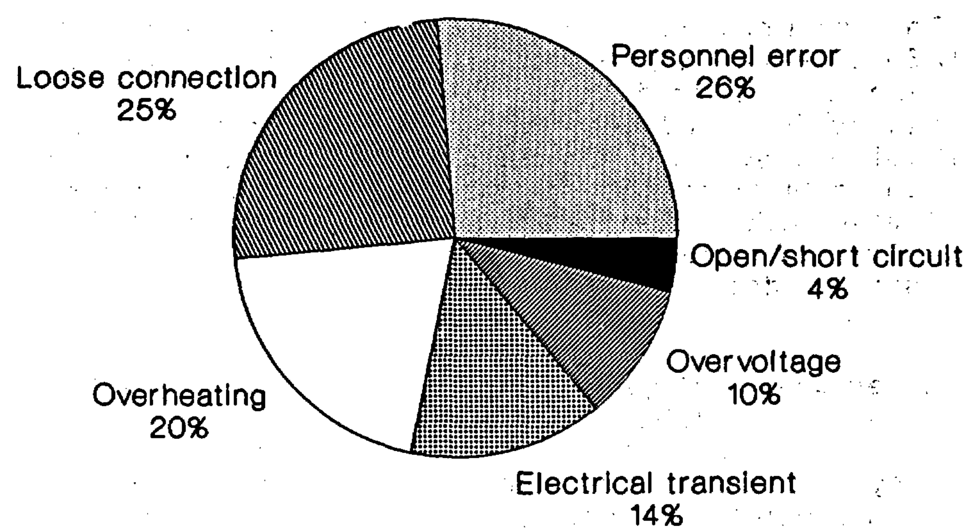
2. **Excessive Ripple:** Failures in the filter network (capacitors and inductors) can create abnormally high ripple voltages on the charger output. This can result in the failure of sensitive electronic instrumentation and can create overheating of the supplied battery.

3. **Loss of Voltage Output:** Battery charger fuse or circuit breaker operation in reaction to normal plant electrical transients and switching have rendered the charger inoperable. The thermal fatigue of fuses with time could increase their propensity to fail in this manner.

OPERATING EXPERIENCE

Chargers are susceptible to failures from overheating and loose connections. Because of their complexity, failures due to personnel error are high. For approximately 40% of the total failures, the cause was not delineated.

IDENTIFIED FAILURE CAUSES



Percent of Failures-LERs 1976 to 1986

SOLUTIONS TO AGING PROBLEMS

DESIGN

The solid-state type charger is most widely used, (75% of chargers) and is the only type qualified to industry standards. The magnetic amplifier and controlled ferroresonant types comprise the remaining population. The following design related solutions primarily address the solid state charger.

1. Battery charger degradation or failure should be annunciated before a decrease in the dc bus voltage occurs. Annunciation of high and low charger output voltage and current are appropriate.
2. Because of its susceptibility to stresses from plant electrical transients, surge suppression schemes should be employed on the power supply to the charger. Auto or isolation transformers i.e., SOLA, have been effective.
3. The availability of a standby battery charger increases the reliability for maintaining the batteries in a fully charged condition.

MAINTENANCE & MONITORING

The battery charger is comprised of several types of subcomponents which require periodic maintenance and monitoring. These components include filter capacitors, thyristors(SCRs), transformers, circuit breakers, and relays. In addition, output metering should be calibrated to permit accurate, routine monitoring.

1. **Filter capacitors:** Capacitors have a limited service life (5 to 10 years) based on the operating temperature and applied voltage. Degradation can be detected through measurement of capacitance or equivalent series resistance, or by deterioration of circuit waveforms. Periodic replacement is also effective in lieu of the detection techniques

(continued)

2. **Thyristors (SCRs):** Large thyristors used in the rectification process are sensitive to temperature. Heat sinks are installed to transfer heat away from these devices. The heat sink surfaces should be periodically cleaned to maintain their design rating. In addition, the connection between the SCR and heat sink should be torque checked.

3. **Magnetics (Transformers and Inductors):** The life of transformers and inductors (chokes) is directly related to their insulation condition. Therefore, the periodic monitoring of insulation resistance (meggar) and winding temperature, is recommended.

4. **Circuit Breakers and Relays:** Periodic manual operation and calibration of the circuit breakers and protective relays (high temperature, abnormal voltage) are necessary to ensure proper operation of these important devices.

5. **Panel Meters:** Instrumentation on a battery charger front panel often includes output voltage and load current. These readings are used by operators on a regular basis to determine equipment operability. Regular calibration is necessary for reasonable accuracy.

MAINTENANCE AND MONITORING
(Continued)

PERIODIC TESTING

Technical specifications require that capacity testing be performed on the station battery and its associated battery charger. For the charger, the test interval is typically every refueling. The capacity test simulates the maximum possible loads, which generally occur when the charger must supply the station dc loads while recharging the depleted battery. During capacity testing, the following additional activities are recommended to determine the charger's condition:

1. The cabinet temperature should be monitored, as well as selected temperature sensitive components.
2. Monitoring the circuit waveforms is recommended to verify proper equipment operation. Changes in waveshape could alert personnel to potential problems, as well as provide troubleshooting guidance. Obtaining waveshape and temperature data at a consistent load is important for trending.
3. Measurement of the ripple voltage on the dc output during periodic testing is important. This value should not exceed 2% of the rated voltage. Damage to the station battery could result.

REFERENCES

1. **IEEE Std. 650-1979,** "IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations."
2. **Information Notice 84-84, rev. 1:** "Deficiencies in Ferro-resonant Transformers," 4/85.
3. **NEMA PE5-1983,** "Constant Potential Type Electric Utility Battery Chargers."
4. **Regulatory Guide 1.32;** "Criteria for Safety Related Electric Power Systems for Nuclear Plants."

AGING REPORT SUMMARY
MOTOR CONTROL CENTERS

SUMMARY

Motor Control Centers (MCCs) are low voltage (<600 volts) controllers that start and stop, provide continuous power to, and protect motors that drive pumps and motor operated valves. Typically, a motor controller unit consists of a molded case circuit breaker, a magnetic contactor, a transformer, relays and thermal overload devices. Age-related degradation of these subcomponents has impacted safety system availability and operation.

BASED ON:

1. **NUREG/CR-5053, *Operating Experience and Aging Assessment of Motor Control Centers, 7/88.***

AGING RELATED PROBLEMS

CONTAM

1. The most frequent cause of MCC failure was the buildup of dirt or other foreign substances that caused the electrical device to stick.
2. More failures occurred in systems that function intermittently rather than continuously.
3. The starter contactor may fail to close due to a non-uniform magnetic driving force caused by impeded armature motion.
4. Most age-related failures are attributed to the circuit breaker and relay subcomponents. Setpoint drift and contact surface degradation are two dominant failure modes.

OPERATING EXPERIENCE

Operational data on nuclear plant components shows there have been significant failures of molded case circuit breakers, relays, and magnetic contactors used in MCCs. The combination of circuit breakers and relays contribute to about 50% of all reported MCC failures. Subcomponent contribution to MCC inoperability, along with the breakdown of the dominant failure modes, are illustrated.

SUBCOMPONENT	*FAILURE MODE CONTRIBUTION*
Circuit Breaker	Failed to close - 32% Tripped - 19% Would not operate - 17% Failed to open - 9%
Relays	Failed to close - 23% Failed to open - 21% Would not operate - 19% Out of adjustment - 11%
Transformers	Short/Ground - 55% Open circuit - 27%
Starter/Contactor	Failed to close - 43% Would not operate - 30% Failed to open - 11%
Overload Device	Tripped - 41% Failed to close - 8% Would not operate - 8%
Coil	Open circuit - 25% Short/Ground - 12% Would not operate - 10%
Control Mechanism	Out of adjustment - 39% Tripped - 26% Open circuit - 13%

SOLUTIONS TO AGING PROBLEMS

DESIGN

At least five different manufacturers supply MCCs to nuclear power plants. Although the outside appearance varies, the basic elements inside the compartment and their designs are the same. Design considerations which are related to the aging process include the following:

1. NEMA standards require that the magnetic devices operate properly at varying voltages from 110% to 85% of the rated coil voltage. Regulating transformers can provide the necessary voltage control to minimize stresses on key MCC subcomponents.
2. MCC enclosures are classified into four categories by NEMA. As a minimum, NEMA 2 drip-tight construction should be used. The doors are gasketed and a drip shield is located on top of the cubicle.
3. For MCCs associated with standby equipment, strip heaters should be considered for the control of moisture intrusion.

TESTING

Several tests are useful in assessing the performance characteristics of the MCC, such as:

1. Continuity test following repair or replacement of a component.
2. Contactor mechanical and electrical checks, including verification of pickup and dropout voltages.
3. Verification of circuit breaker trip setpoint. Compare timing with manufacturer's data.
4. Testing of time delay relays where applicable.
5. A final energized operational test of each control device.

SOLUTION TO AGING PROBLEMS
(continued)

PERIODIC MAINTENANCE

Based on the input received from manufacturers and utilities, several maintenance actions are recommended to detect and mitigate age related degradation.

MCC COMPONENT	*MAINTENANCE ACTION*
Structure	Check for moisture, oil, and foreign material. Vacuum clean.
Bus Bar	Examine for pitting, corrosion, and overheating. Check connections for tightness.
Circuit Breaker	Test and examine for proper operation.
Operating Mechanism	Exercise ON, OFF, RESET buttons; verify interlocks.
Fuses	Check for arcing or overheating
Starter	Inspect contacts and replace if pitted or corroded.
Overload Heater	Manually trip the device and inspect for proper operation. Check size of heater.
Metering	Calibrate important indicators
All Components	Inspect connections for tightness; inspect wiring for signs of wear and overheating.

REFERENCES

1. **Information Notice 86-66;** "Potential for Failure of Replacement AC Coils Supplied by the Westinghouse Electric Corporation for Use in Class 1E Motor Starters and Contactors."

2. **NEMA AB-1;** Molded Case Circuit Breakers

3. **UL 845;** Motor Control Centers

4. **IEEE Std. 649;** "IEEE Standard for Qualifying Class 1E Motor Control Centers for Nuclear Power Plants"

AGING REPORT SUMMARY

COMPONENT COOLING WATER (CCW) SYSTEM-PWRs

SUMMARY

The CCW System in a PWR is a continuously operating non-radioactive closed loop system used to remove heat from plant equipment, and transfer it to an open loop cooling system such as service water. Aging is a significant factor in failures of CCW systems (over 70% of the failures reported were related to aging). Fifty percent of the the failures resulted in degraded performance of the CCW system, while 27% caused a loss of redundancy. Using the time dependent failure rates calculated from the plant data, improvements in maintenance and monitoring methods may be required to prevent system unavailability from reaching an unacceptable level during the later years of plant life.

BASED ON: NUREG/CR-5052, "Operating Experience and Aging Assessment of Component Cooling Water Systems in Pressurized Water Reactors", 7/88.

AGING RELATED PROBLEMS

WEAR → Leakage

Leakage was the predominant mode of failure. Wear was the predominant failure mechanism. On a component level, valves were the most commonly reported component to fail. These were dominated by failure of the valve operators, followed by wear of the valve seats. Pump failures were dominated by seal and bearing failures, while heat exchanger failures most frequently involved the tubes. Factors contributing to aging of these components along with the observed effects are summarized on the next page.

AGING RELATED PROBLEMS
(Continued)

Under normal operating conditions, the stresses which contribute to CCW system aging, and the part of the system it most affects are summarized:

AGING EFFECTS	COMPONENTS AFFECTED
Erosion, wear, corrosion	***Mechanical***
Clogging, blocking, reduced flow	***Mechanical***
Vibration, misalignment, loose parts	***Mechanical, electrical, instrumentation & controls***
Binding, distortion, rupture	***Mechanical***
Electrical short circuits, grounds, pitting	***Electrical, I&C***
Setpoint drift, loose connections	***Electrical, I&C***

OPERATING EXPERIENCE

For each CCW component showing a significant number of failures, the data were examined to identify the specific subcomponents which failed. As illustrated below, pump seals and bearings contributed most to pump unavailability. Similarly, valve operators and valve seats were the leading subcomponent problems leading to CCW valve failures.

Subcomponent Failures:

PUMPS:
- Seals - 57%
- Bearings - 25%
- Other - 18%

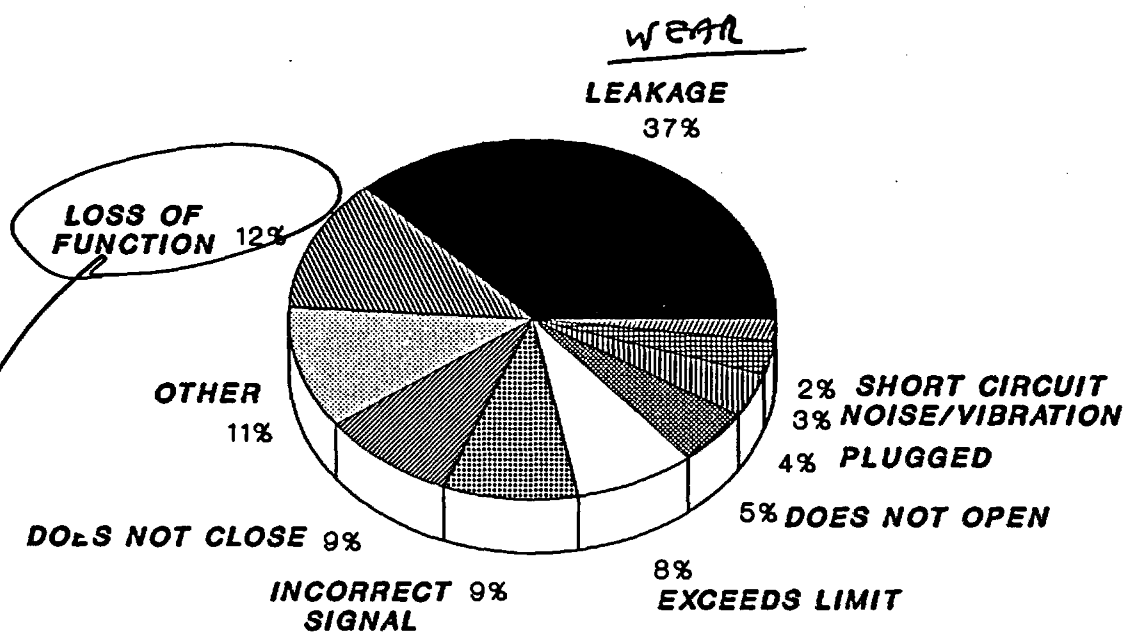
VALVES:
- Operator - 39%
- Seat - 31%
- Other - 30%

HEAT EXCHANGER:
- Tubes - 59%
- Other - 25%
- Tubesheet - 16%

OPERATING EXPERIENCE

(Continued)

The failure modes for the CCW system are diverse. Leakage is the most common mode of failure and is typical for pump and valve failures. The failure modes classified as "other" include overload, rupture, and disengaged.



The predominant failure mechanism for the CCW system is wear, which accounted for 37% of the reported failures. The other 63% of the failures were distributed fairly evenly among the mechanisms listed below. "Fracture" includes events where fracture or crack growth lead to failure. The "contamination" category includes failures where a foreign material was introduced into the system causing a blockage or buildup. "Calibration" includes failures where set point drift occurred, often resulting in a violation of technical specifications.

FAILURE MECHANISMS

Wear - 37%
Calibration - 12%
Contamination - 9%
Other - 8%

Corrosion/erosion - 8%
Distortion - 7%
Deterioration - 7%
Fracture - 2%

SOLUTIONS TO AGING PROBLEMS

Aging contributes to a significant portion of CCW system failures. Monitoring methods must, therefore, include good functional indicators which will detect aging effects while the system operates normally. It would then be possible to mitigate aging effects.

1. Because leakage is a typical failure mode associated with both pump and valve failures, it suggests that inspecting and testing for leakage are important monitoring methods.
2. The variety of failure modes suggests that several different monitoring techniques would be required to detect all failures. For example, visual inspections could only be expected to detect a portion of the CCW system failures. A good surveillance and monitoring plan should be diverse, and include sufficient tests and inspections to cover all of the significant failure modes.

The functional indicators recommended as potentially viable methods for monitoring and detecting aging degradation are:

	STRESSORS	AGING EFFECTS	FUNCTIONAL INDICATORS
CCW VALVES	**High temp.** **Foreign materials** **Humidity, dust** **Cyclic operation**	**Packing & seat leakage** **Stem binding** **Insulation degradation** **Erosion/ corrosion**	**Visual inspection** ***Leakage tests*** ***Stem torque check*** ***Torque/limit switch setting*** ***Current/voltage monitoring***
CCW HEAT EX.	**High press.** **High flow** **Service water exposure**	**Fouling of surfaces** **Erosion/ corrosion** **Blockage**	**Visual inspection** ***Temperature*** ***Acoustic or eddy current tests*** ***Bolt torque check***

SOLUTIONS TO AGING PROBLEMS

(continued)

	STRESSORS	AGING EFFECTS	FUNCTIONAL INDICATORS
CCW PUMPS	Vibration High Temp. Human Error Loss of NPSH	Bearing Wear Distortion Cavitation Seal & Packing Wear	*Vibration Rdgs.* *Lube Oil Temp., Quality, & Level* *Bearing Temp.* *Visual Insp. for leaks*

SYSTEM LEVEL INDICATORS ⇒ *Surge Tank level, system flows and pressures, HX. outlet temps.*

REFERENCES

1. Bulletin 88-04, "Potential Safety Related Pump Loss", 5/88.
2. NUREG - 0800, Standard Review Plan, Section 9.2.2; "Reactor Auxiliary Cooling Water Systems", 6/86.
3. ASME/ANSI OM-1987, Part 2-Appendix D; "Guidance for Analyzing System Degradation"
4. Generic Issue 65 - CCW Supply to the Reactor Coolant Pump Seals

AGING REPORT SUMMARY

RESIDUAL HEAT REMOVAL (RHR) - BWRs

SUMMARY

The RHR System in a BWR serves a variety of purposes for operation during routine, abnormal, and emergency conditions. While the failure data reviewed covered all phases of operation, the emphasis of evaluating system effects and operating stresses was on the Low Pressure Coolant Injection (LPCI) and Shutdown Cooling (SDC) operating modes. Aging has a moderate impact on RHR component failure rates (0 to 17% per year increase). Standby systems such as RHR may be less severely affected by aging, although several plants exhibit increasing failure trends for certain RHR components.

BASED ON: NUREG/CR-5268, "Aging Study of Boiling Water Reactor Residual Heat Removal System", 6/89.

AGING RELATED PROBLEMS

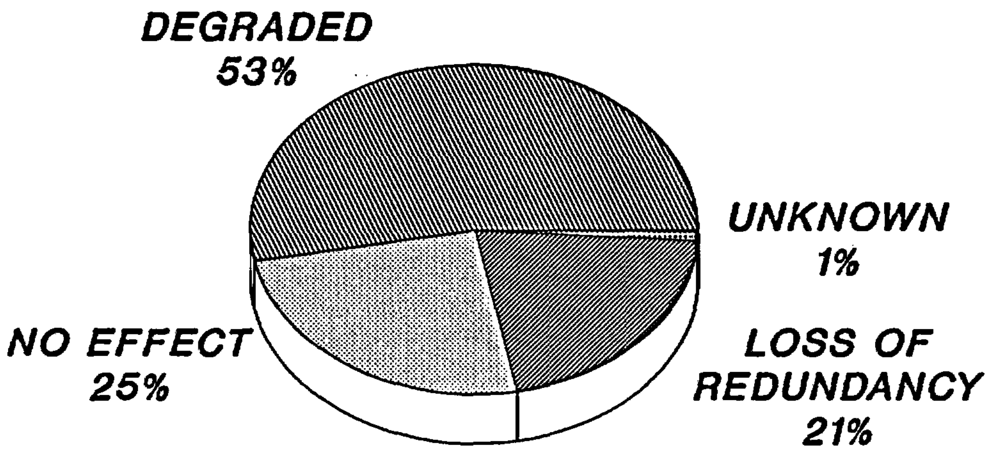
Aging is a concern for RHR systems. The evaluation of multiple data bases showed that more than 50% of the failures were attributed to aging. Different aging mechanisms are present, related to the operating status of the system. While in standby, the aging mechanisms are:

* corrosion
* set point drift
* embrittlement

Aging degradation due to wear takes place while the system is in the shutdown cooling or testing mode. Operational stresses are enhanced by the synergistic effects of various standby stresses. One important source of stress is testing. Plants with a common minimum flow line for 2 RHR pumps, for instance, should closely monitor pump performance since aging can degrade performance, and lead to dead-headed pump operation on one of the pumps. This can result in overheating and premature failure.

OPERATING EXPERIENCE

The effect of each RHR failure on system performance was determined from the NPRDS data. Over half of the failures resulted in degraded operation of the system. This implies that the system can still perform its function; however if left uncorrected, the failure could cause a loss of system function.



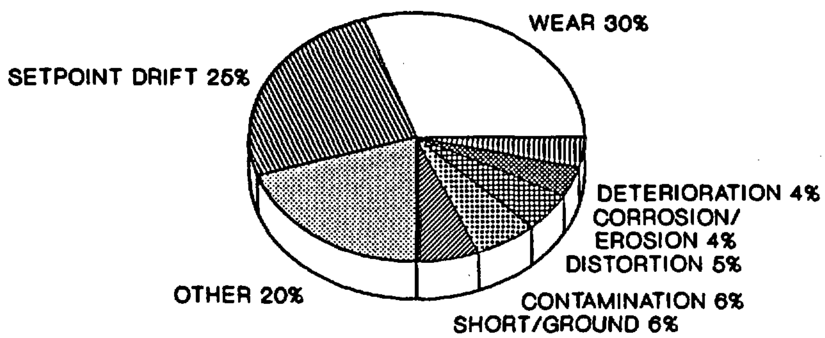
No failures were reported in which the complete loss of LPCI resulted. However, the complete loss of the shutdown cooling mode of RHR resulted from some of the component failures. These typically involved a failure of the instruments controlling the inboard or outboard isolation valves, or a failure of the valves themselves.

FAILURE MECHANISMS:

A failure mechanism is the physical, chemical, or other process by which a component or system degrades or fails. Since the RHR system has standby modes as well as operational modes, there are several different failure mechanisms. Wear represents an exposure to stresses encountered during operation, which results in some portion of the component being worn away. The failure mechanism classified as Other includes embrittlement, fatigue, vibration, and fracture. Deterioration includes failures where a material of construction is broken down physically by the environment to a point where it can no longer perform its function; i.e. insulation or gaskets.

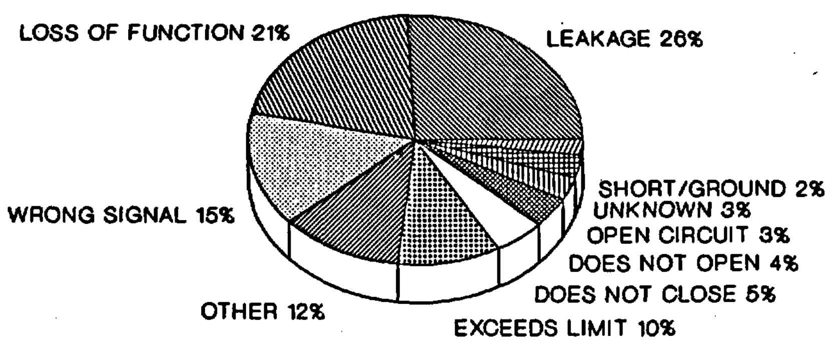
OPERATING EXPERIENCE
(continued)

RHR FAILURE MECHANISMS:



FAILURE MODES:

A failure mode is the manner in which a component fails. The failure modes for the RHR system are diverse. The predominant modes include Leakage, Loss of Function, and Wrong Signal. Leakage includes internal and external leakage of valves, along with leakage of pump seals, piping and pipe fittings. The Loss of Function mode includes failure of an instrument to operate or failure of a pump to run. The Wrong Signal mode includes a position switch indicating a valve is closed when it is actually open, or a pressure transmitter indicating the incorrect pressure.



RHR FAILURE MODES

SOLUTIONS TO AGING PROBLEMS

The operational readiness of the RHR system can best be assured from three tests:

1. *Valve stroke tests*
2. *Control logic response tests*
3. *In-service inspection pump tests*

This choice is supported by the data which showed valves and instrumentation/controls to be the two predominant types of components in the RHR system which fail.

The type and amount of periodic testing, preventive maintenance, and corrective maintenance performed on the major system components are described in the following summary:

RHR PUMPS:

TESTING

During the quarterly testing required by tech. specs. for RHR pumps, it is recommended that other information is recorded such as bearing vibration and temperature, motor amps and voltage, and motor winding temperature.

Bearing degradation can be detected by increasing vibration and temperatures. Likewise, motor and pump degradation may be apparent from increasing motor current or winding temperatures.

PREVENTIVE MAINTENANCE

Due to environmental qualification requirements, bearings, seals, and gaskets are replaced at prescribed intervals. Activities such as cleaning and lubrication should be periodically conducted regardless of whether the pump is in standby or is continuously operating.

The frequencies at which PM activities are performed are normally based on the equipment's operating experience, plant configuration, and the impact of pump failure on plant risk. The limited PM activities described may be justified based on the extent of periodic testing that is performed.

SOLUTIONS TO AGING PROBLEMS
(continued)

RHR VALVES:

TESTING

In accordance with tech. specs., periodic testing is required for key RHR valves, including measurements of valve stroke time and valve seat leakage. Technical specifications also requires that each valve in the flow path be periodically checked to verify its correct position. Other periodic testing that utilities have successfully employed to monitor valve degradation are:

1. *Relief valve setpoint verification (5 years)*
2. *MOV signature analysis (18 months)*
3. *Position indicator functional test (18 months)*

As a result of numerous problems with MOVs, further research is being conducted. Stroke time testing may be of only limited value, and the frequent operation required by testing may result in accumulated wear to the valve seats. NRC Generic Letter 89-10 addresses this concern.

PREVENTIVE MAINTENANCE

Utility practices for RHR valve PM consist primarily of inspection and lubrication. The frequency of this activity ranges from annually to every four years. Some utilities also periodically megger the motors on the MOV. Inspection and lubrication of manual and check valves are also performed. PM on AOVs and SOVs is largely based on EQ requirements.

It should be noted that post maintenance testing is performed for valves, especially MOVs. Following packing adjustments or torque/limit switch corrections, stroking the valve is useful to verify proper operation.

SOLUTIONS TO AGING PROBLEMS
(continued)

RHR HEAT EXCHANGERS:

TESTING

In-service testing, such as a heat balance, is a standard non-intrusive test for determining heat exchanger capacity. Design calculations assume a certain amount of fouling; the heat balance determines the continued validity of the assumption. Other periodic tests such as a hydrostatic or leak test verify the integrity of the pressure boundary interfaces. Research is continuing to determine the effectiveness of other methods such as eddy current and acoustic testing.

PREVENTIVE MAINTENANCE

The preventive maintenance activities specified for the RHR heat exchanger includes inspection, tube cleaning, and a periodic replacement of gaskets.

REFERENCES

1. Bulletin 88-04, "Potential RHR Pump Loss"
2. Generic Letter 89-10, "Safety-Related Motor Operated Valve Testing and Surveillance"
3. Bulletin 86-01, "Minimum Flow Logic Problems That Could Disable RHR Pumps"
4. Notice 86-36, "Failure of RHR Pump Motors and Pump Internals"

APPENDIX B

AGING INSPECTION GUIDES

AGING INSPECTION GUIDE-*INVERTERS*

I. Visual Inspection: Summary

a. External

1. There is no unusual meter oscillation or electrical hum
2. The input and output parameters fall within specifications (voltage, current, frequency)
3. The cooling air filters are not clogged

b. Internal

1. There are no signs of overheating
2. The capacitors are not bulging or leaking oil
3. The panel is clean, especially SCR heat transfer surfaces

II. Understanding and Managing Aging

a. Maintenance Activities

1. Periodic inspections are performed and include cleaning and checks of connection tightness

2. Preventive maintenance is conducted at least once per cycle and includes calibration, EQ related component replacements, and evaluation of circuit waveforms. Electrolytic capacitors should be included in the EQ program.

3. The personnel responsible for maintenance have been trained, and use approved procedures which have incorporated the vendor's recommendations.

b. Operations Related Activities

1. The daily logs or round sheets include recording the data on or observing inverter performance

2. The operating procedures address the response to an inverter failure

3. Periodic checks are made to insure proper electrical alignment - normal supply from the station battery

AGING INSPECTION GUIDE-*INVERTERS*
(continued)

c. Design/Test Related Activities

1. The loading of the inverter for normal and postulated accident conditions is within the equipment's rating.
2. The static switch is functionally tested to assure an uninterruptible transfer to alternate supply.
3. Capacity testing, especially recommended for standby inverters, accurately reflects loads.
4. A protective device coordination exists between the inverter and its branch circuits.

d. Other Recommended Licensee Activities

1. Replacement or testing of all filter capacitors should be considered when one fails. (Same stress)
2. The ferro-resonant inverters (i.e., SCI, Westinghouse) use magnetic components for waveform shaping and voltage regulation. Special ferro tuning techniques recommended by the manufacturer should be followed.
3. The pulse-width modulated inverters (i.e., Elgar, Cyberrex) generate a near sine wave output through electronic feedback. Photographing the wave shapes for timing and sequence should provide good trouble shooting information.

AGING INSPECTION GUIDE
MOTORS

1. Visual Inspection Summary

a. *Operating Parameters Routinely Observed*

1. Bearing vibration and temperature
2. Lube oil level and appearance
3. Winding temperature (permanently installed detectors may be recorded by plant computer or data logger)
4. Motor line current-concern for motor overload
5. High noise level-indicator of poor alignment, excessive friction

b. *External Indicators or Causes of Age Degradation*

1. Humidity - the space heaters should be energized on standby motors
2. Dust & Dirt Buildup - Internal air temperature may be too high due to blocked air passages or dirty filters
3. Ambient Temperature - motor insulation class (rating) limits safe ambient temperature
4. Corrosion or surface cracks
5. Loose mechanical connections

2. Licensee Program Evaluation for Understanding and Managing of Aging

a. *Maintenance Activities*

1. During scheduled downtime, ventilation openings filters and winding insulation are cleaned.
2. Vibration levels are measured and evaluated routinely.
3. There is a greasing schedule for anti-friction bearings. Oil changes for sleeve bearings are similarly scheduled.
4. Oil leaks are corrected expeditiously to avoid winding contamination.
5. Manufacturer recommended maintenance such as replacing seals or carbon brushes are evaluated and incorporated into the maintenance program.

MOTOR INSPECTION GUIDE
(continued)

b. Operations Related Activities

1. The line current is measured and recorded periodically during motor operation.
2. Operating rounds include observations of space heater energization for standby motors.
3. Operating procedures contain guidance for the number of starts permitted over a given time.
4. Alarm response procedures address the operator's action to abnormal motor conditions.

c. Design/Test Related Activities

1. Periodic surge tests or partial discharge (corona) tests are conducted to monitor age-related deterioration.
2. Large motor operating hours are monitored (elapsed hour counter on switchgear).
3. Motor operating parameters are monitored, recorded, and evaluated, when performing required surveillance testing on pumps and valves.
4. AC/DC leakage (hipot) testing is not recommended.
5. An engineering evaluation of base-line readings for bearing vibration, motor winding temperature, and rated current values has been completed.

AGING INSPECTION GUIDE-*BATTERY CHARGERS*

I. Visual Inspection Summary

a. External

1. The identification of positive output current
2. No unusual meter oscillation or electrical hum is apparent
3. The charger output voltage is correct
4. The cooling air filters are not clogged
5. The ambient temperature of the room is less than 90F

b. Internal

1. There are no signs of overheating
2. The capacitors are not bulging or leaking oil
3. The panels are clean especially SCR heat transfer surfaces

II. Licensee Program Evaluation for Understanding and Managing Aging

a. Maintenance Activities

1. Periodic inspections are performed and include cleaning & checks of connection tightness

2. Preventive maintenance is conducted at least once per cycle and includes calibration of panel meters and alarm/trip relays.

3. The personnel responsible for maintenance have been specifically trained on this equipment.

b. Operations Related Activities

1. The daily logs or round sheets include recording of the charger output voltage and current

2. The operating procedures address the response to a battery charger failure.

3. Periodic checks are made to insure proper electrical alignment. The normal supply to the dc bus is from the charger.

AGING INSPECTION GUIDE-*BATTERY CHARGERS*

(continued)

c. Design/Test Related Activities

1. Capacity testing is performed in accordance with the tech. specs. (typically, every refueling)
2. Circuit waveforms are observed and recorded to verify proper operation of key components. Comparison of waveforms to previous testing is recommended.
3. Capacity testing, even for standby chargers, represents worst case load situations.

d. Other Recommended Licensee Activities

1. Replacement or testing of all filter capacitors should be considered when one fails. (Same stress)
2. Modifications affecting the dc bus should include an evaluation of the impact on the battery charger
3. The structural integrity of the chargers should be periodically checked, based on seismic requirements and vulnerability.

AGING INSPECTION GUIDE
MOTOR CONTROL CENTERS

I. Visual Inspection Summary (Primarily Internal)

1. There are no signs of overheating
2. The MCC is clean, especially the contact surfaces
3. There is no moisture, oil, and foreign material
4. The cubicle is in operable status

II. Licensee Program Evaluation for Understanding and Managing Aging

a. Maintenance Activities

1. A physical inspection of the MCC should be conducted periodically including:
   * check the terminal block condition and connection tightness.
   * check the condition of the mechanical linkages and electrical insulation.
   * check that there is no moisture, oil, and foreign material
   * examine contacts and fuses for pitting, corrosion, and signs of overheating.
2. Preventive maintenance should include the following activities:
   * calibration of metering and verification of the size of the overload heater.
   * exercise the operating mechanism, including the manual trip button.
   * an insulation test (megger) is recommended following the completion of maintenance.
   * check the pickup and dropout voltages to monitor deterioration of coils

AGING INSPECTION GUIDE-*MCCs*
(continued)

c. Design/Test Related Activities

1. A cycle counter is useful for determining PM frequency. The wear on many parts is directly related to the number of operating cycles.
2. The trip setpoint of the circuit breaker should be checked at least every five years to minimize the effects of setpoint drift.
3. Because of the effect of the motor applications on the sizing of the overload heater, documentation should exist to support the selected value.
4. Tech. Spec. compliance at some plants requires that a functional test of 10% of the MCCs be conducted along with preventative maintenance on each MCC breaker every 5 years. Additional testing is required if a failure occurs.

d. Other Recommended Licensee Activities

1. The daily logs or round sheets should include observations of MCC status and condition, especially those located in harsh environments.

AGING INSPECTION GUIDE
COMPONENT COOLING WATER SYSTEM

Because there are many variations in the design of CCW systems, the impact of a component failure on the system's performance will vary. For instance, five 2-unit sites have a fully shared system with 5 pumps, 3 heat exchangers, and 2 surge tanks. A single component failure has little impact because of the extra redundancy. However, multiple component failures could affect both units. Differences in designs results in differences in emphasis and the priority of licensee resources.

1. Visual Inspection Summary

a. Major valves are monitored for leakage & appearance.
b. Heat exchangers are inspected for leakage, temperature.
c. Steady state flow to critical loads is checked:
   * Reactor coolant pump (RCP) seals.
   * Residual Heat Removal (RHR) heat exchangers and pump seals.
   * Safety Injection (SI) pump & motor coolers.
   * Chillers & Containment coolers.

2. Licensee Program for Understanding & Managing Aging

a. *CCW Pumps:*

* Trend the pump's performance (flow, pressure)
* Monitor the bearing temp. & vibration (operator rounds)
* Perform analysis of lube oil quality

b. *CCW Heat Exchangers:*

* Trend the inlet and outlet temperatures
* Perform eddy current or acoustic testing (or equivalent) to determine tube sheet condition

c. *CCW Valves:*

* Calibrate the control valves, check set points
* Monitor the operator current/voltage

d. ***Other CCW System Activities:***

* The integrity of the piping should be checked periodically, especially main headers.
* The instrumentation (controls, indicators) associated with modulating flow to equipment should be calibrated regularly.
* The strainers in the system (pump suction) should be cleaned, based on differential pressure readings.
* Water chemistry should be routinely checked, and chemical addition modified as necessary.

AGING INSPECTION GUIDE
RESIDUAL HEAT REMOVAL SYSTEM

1. Visual Inspection Summary

a. When in the standby mode, the pump areas are checked for environmental conditions; temp., cleanliness
b. When a pump is operating, vibration levels, motor amps, and motor winding temps. are observed
c. The major valves are monitored for leakage and appearance.
d. The heat exchangers are inspected for leakage, temperature.

2. Licensee Program for Understanding & Managing Aging

a. RHR Pumps:

* Trend pump performance (flow, pressure)
* Monitor bearing temp. & vibration (periodic testing)
* Perform an analysis of lube oil quality
* Monitor and trend motor performance (amps, windings)

b. RHR Heat Exchangers:

* Trend the inlet and outlet temperatures
* Perform eddy current or acoustic testing (or equivalent) to determine tube sheet condition

c. RHR Valves:

* Monitor the operator current/voltage
* Check the relief valve setpoints
* Perform post maintenance testing following corrective maintenance activities
* Trend the results of the tech. spec. tests

d. RHR Instrumentation

* Routinely calibrate the instrumentation channels, especially those associated with system actuation, isolation and permissives.
* Properly fill and vent the instruments following testing or maintenance.

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11. ABSTRACT *(200 words or less)*

The US NRC's Nuclear Plant Aging Research (NPAR) Program has determined the susceptibility to aging of components and systems and the potential for aging to impact plant safety and availability. The NPAR Program also identified methods for detecting and mitigating aging in components.

This report describes the NPAR results which can enhance NRC inspection activities. Recommendations are provided for communicating pertinent information to NRC inspectors. These recommendations are based on a detailed assessment of the NRC's Inspection Program, and feedback from resident and regional inspectors as described within. Included are NPAR report summaries and aging inspection guides for components and systems which have been evaluated at BNL.

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